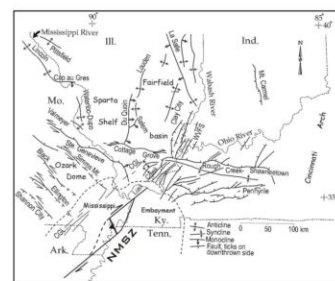


# A Strategy for Assessing Deep Faulting and Possible Structural Reactivation in Target Sequestration Reservoirs

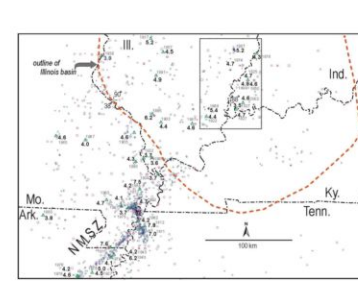
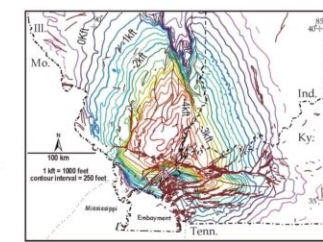
J. H. McBride, Department of Geological Sciences, Brigham Young University, Box 24606, Provo, UT 84602; Illinois State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820  
H. E. Leetaru, Illinois State Geological Survey, 615 E. Peabody Dr. Champaign, IL 61820

**Abstract.** The investigation of deep fault structure and seismogenesis within "stable" continental interiors has been hindered by the paucity of detailed subsurface information and by low levels of seismicity. Outstanding seismotectonic questions for these areas include whether pre-existing structures govern the release of seismic energy as earthquakes, can reactivation of such structures be recognized, and to what extent have Precambrian basement structures exerted long-lived controls on the development of overlying Phanerozoic features. The southern Illinois basin provides a premier area in which to study the relation between contemporary seismicity and pre-existing structures due to the frequency of seismic events, the concentration of available geophysical data, and the wealth of borehole information. We have integrated the study of this information in order to create a 2.5-dimensional picture of the earth for local seismogenic depths (0-15 km) for a case study area of moderate 20th century earthquake activity. The area is located along the western flanks of two of the major structures within the Illinois basin, the Wabash Valley fault system (WVFS) and the La Salle anticlinal belt (LSA). The results of reprocessing seismic reflection profiles, combined with earthquake hypocenter parameters, reveals three distinct seismo-tectonic environments in the upper crust. First, we have delineated a fault pattern that corresponds to the steep nodal plane of a strike-slip mechanism event (1974.04.03;  $m_b = 4.7$ ). The fault pattern is interpreted to be a deeply buried rift zone or zone of intense normal faulting underpinning a major Paleozoic depositor of the Illinois basin (Fairfield sub-basin). Second, a similar event (1987.06.10;  $m_b = 5.2$ ) and its well located aftershocks define a narrow zone of deformation that occurs along and parallel to the frontal thrust of the LSA. Third, the hypocenter of the largest event in the study area (1968.11.09;  $m_b = 5.5$ ) corresponds to a prominent zone of dipping middle crustal reflections, just west of the WVFS, which have been interpreted as a deeply buried blind thrust. The correlations of pre-existing structures with consistently oriented earthquake structural parameters demonstrates the reactivation of "old" deformation zones by contemporary stresses. However, the degree to which deformation has propagated upward from Precambrian basement into the Paleozoic rocks varied significantly even over a small study area. The value of associating an earthquake event with an image of a pre-existing deformation zone in the seismogenic crust is to improve the assessment of seismic hazard (by pin-pointing potentially hazardous faults) or to assess the integrity of a stratigraphic formation, underlain by a basement fault, that is under consideration as a target for natural gas storage or CO<sub>2</sub> sequestration.

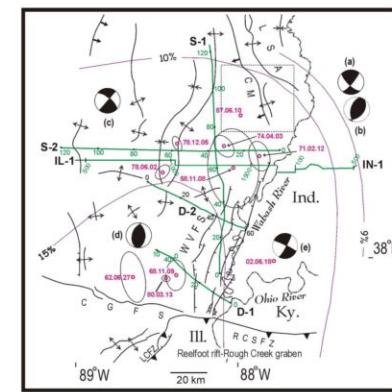
Structural configuration of the southern Illinois Basin shown by contours representing the depth to the base of the Up. Devonian New Albany Shale (contour interval is 250 feet below sea level; original units) and by structural axes (faults and folds). Source: Gas Research Institute, Chicago, IL.



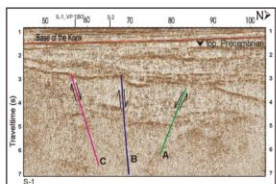
Structural setting for the Illinois Basin WVFS is Wabash Valley fault system, CGL is Commerce geophysical lineament, NMSZ is New Madrid seismic zone.



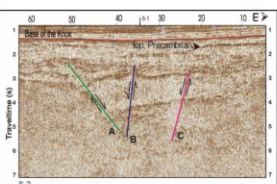
Central U.S. earthquakes through 2004. Sources: (1) the "Catalog of Central U.S. Earthquakes, 1810-1980" by Nuttli and Brill (with body wave magnitude of at least 2.4; 1811-1973); (2) instrumental data from the Center for Earthquake Research and Information (with body wave magnitude of at least 2; 1974-2004). The above two data bases are represented by red and blue circles, respectively; circle size provides a relative measure of magnitude (see original sources for actual magnitudes). The labeled black diamonds show the epicenters for events relocated by the USGS for the Wabash Valley fault zone region. Green triangles are from the data base of relocated events by W. Bakun (USGS) (date and moment magnitude are given), with the exception of the 1968, 1974, and 1987 events as plotted from other sources. Dotted rectangle gives study area.



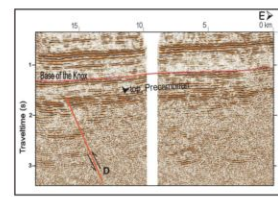
Map of the south-central Illinois Basin and Wabash Valley fault system (WVFS), known fold axes, faults, and other structures, and revised, instrumentally recorded epicenters ( $m_{max} \geq 3.0$ ) with nominal 95% confidence ellipses from the USGS and other sources. CM is Charleston monocline; LSA is LaSalle anticlinal belt; WVFS is Wabash Valley fault system; CGFS is Cottage Grove fault system. Simplified contours show seismic hazard surrounding the New Madrid seismic zone as peak acceleration ( $\%g$ ) with a 10% probability of exceedance in 50 years (see NEHRP B-C boundary) (USGS). Seismic reflection profiles used in this study are also shown. All but IL-1 and IN-1 are proprietary and are depicted in a general way only with kilometer locations marked every 20. Dashed box indicates area of a home network of proprietary profiles ( $\sim 140$  km of line, total), which cannot be shown due to confidentiality agreements. Earthquake focal mechanisms are plotted from Taylor *et al.* (1989; Seismol. Res. Letters), and other sources: (a) main shock of 1987 event (87.06.10), (b) typical reverse-fault aftershock of 1987 event (87.06.10), (c) main shock of 1974 event (74.04.03), (d) main shock of 1968 event (68.11.09), (e) main shock of 2002 event (02.06.10).



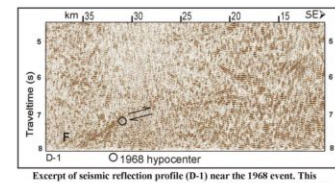
High-resolution (i.e., color amplitude) raster display of an excerpt of the S-1 profile showing the area of intense disruption within the Precambrian section oriented perpendicular to S-1 profile. Seismic data provided courtesy of Seismic Exchange, Inc. to the Illinois State Geological Survey. The interpretation is the responsibility of the authors.



Same as in to the left, but showing S-2 profile for the area of intense disruption within the Precambrian section oriented perpendicular to S-2 profile. Seismic data provided courtesy of Seismic Exchange, Inc. to the Illinois State Geological Survey. The interpretation is the responsibility of the authors.

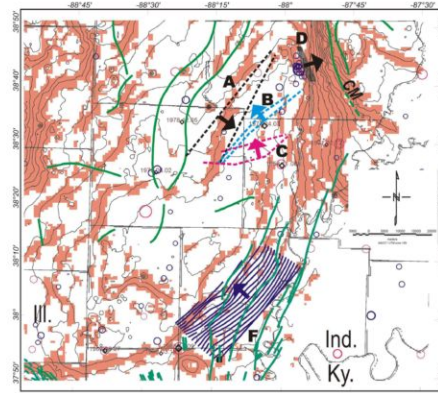


Excerpt of seismic reflection profile located just off the western flank of the Charleston monocline: east-west profile showing the area of folded Paleozoic strata located basin-ward (i.e., to the west) of the Charleston monocline and the interpretation of a basement fault that facilitates the folding above. Seismic data released to the Illinois State Geological Survey.

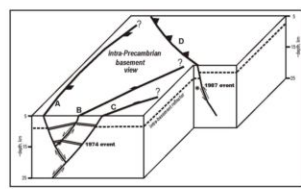


Excerpt of seismic reflection profile (D-1) near the 1968 event. This figure is based on that released in McBride (1998; Geotitles). Seismic data released to the Illinois State Geological Survey.

First derivative ("slope") maps computed using the Barlow Formation surface. The orange shading represents areas of relatively steep slope values. Green lines depict structural axes and faults (from USGS, 2005).



Map of study area with fault zones (A, B, C shown as dashed lines indicating the boundaries) as mapped from the seismic reflection profiles projected onto a base map with county and state lines. Configuration of the mapped fault zones is preliminary. Since the faults are defined only by the available seismic profiles, they are shown cut-off on their ends where no data are available. Also shown are contour lines for fault zone mapped near the 1968 event (F, contour interval = 0.1 s) and fault zone mapped near the 1987 event (D, contour interval = 0.3 s). Bold colored arrows indicate approximate direction of dip of fault surface. Light black lines show Barlow Formation surface contours (thin black lines, feet, depth below sea level; see principal map figure for contour labels) and slope map results. Major structural axes are shown as green lines.



Left, Cartoon diagram of basement structure for the interpreted zone of rifting beneath the Fairfield sub-basin and zone of faulting just west of the frontal thrust of the La Salle anticlinal belt (locally, Charleston monocline). Right, Interpretive cross-section through the region of the 1968 earthquake (modified from McBride *et al.*, 2002, Seismol. Res. Letters). Dashed lines are speculative.

